General Services Administration
Public Buildings Service

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LIGHTWEIGHT QUAD-PANE WINDOWS

Same Thickness as Double-Pane but with 24% more Energy Savings

Double-pane windows have been the industry standard for decades. They represent a vast improvement over single-pane windows but the potential for even greater energy savings with more highly insulting windows has been elusive. Recent price reductions in the thin glass used in both smartphones and flat-screen TVs, as well as in the krypton gas used in halogen lights, however, have made it possible to build lighter, high-efficiency quad-pane windows at a lower cost. Researchers from the National Renewable Energy Laboratory evaluated two configurations of quad-pane windows at an office building at the Denver Federal Center. Both configurations have the same thickness and a comparable weight as a standard commercial double-pane window—one model uses two layers of film suspended between two panes of standard glass, the other replaces the film with two panes of ultra-thin glass. Researchers found that on average, quad-pane windows saved 24% heating and cooling energy compared with a high-performing double-pane window. For new construction and window replacements, the quad-pane windows have payback between one and six years, depending on climate zone and utility rates, and are recommended throughout the GSA portfolio.

The GPG program enables GSA to make sound investment decisions in next-generation building technologies based on their real-world performance.

INTRODUCTION

"These quad-pane windows provided better thermal insulation and because they have the same weight and thickness as a double-pane window they were easy to install. By improving the building envelope, they can help contribute to our net-zero goals."

–Tyler Cooper
Supervisory Energy Project Manager
Denver Federal Center
U.S. General Services Administration

HIGH-PERFORMANCE DOUBLE-PANE

U-Factor (rated)	0.32
R-Value (rated)	3.1
SHGC	0.27 / 0.40
CR (recommended)	50+

QUAD-PANE THIN GLASS

U-Factor (rated/measured)	0.12 / 0.17
R-Value (rated/measured)	8.3 / 5.9*
SHGC	0.20 / 0.46
CR	67**

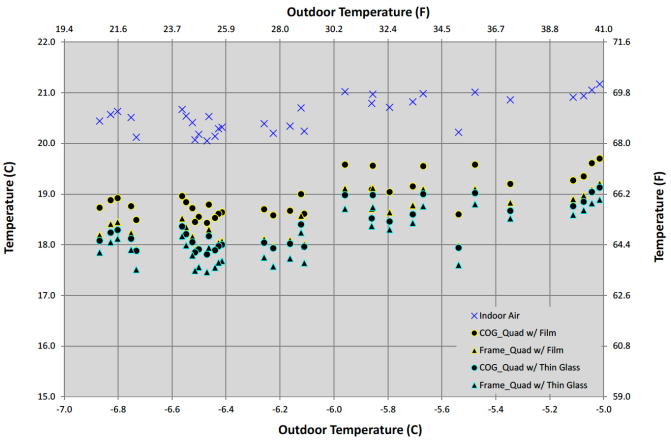
QUAD-PANE SUSPENDED FILM

U-Factor (rated/measured)	0.12 / 0.15
R-Value (rated/measured)	8.3 / 6.8
SHGC	0.19 / 0.38
CR	63-65

*Steel spacers were used in the testbed demonstration due to manufacturing restrictions. Warm-edge spacers would increase the measured U-Factor and R-Value for the thin-glass configuration.

**The manufacturer estimates that warm edge spacers would increase thin glass CR to 80.

Interior Surface Temperatures Stay Warm
When the outdoor temperature was 21°F, the center of glass temperature of the quad-pane with film was 66°F and the frame was 65°F. The temperature for both the frame and the center of glass in the thin-glass configuration was 65°F.



What Is This Technology?

QUAD-PANE WINDOWS WITH SUSPENDED FILM OR THIN GLASS

This study assessed two types of quad-pane windows. One type contains two layers of low-e coated polyester film suspended between two standard panes of window glass; the other replaces the film with two panes of thin glass. The frames are made of insulated pultruded fiberglass. Both configurations typically use warm-edge spacers and are filled with inert krypton gas. Krypton gas is a better insulator than the more commonly used argon gas but until recently has not been as readily available. With the market switching from halogen lighting to LED, krypton availability has increased and the price has dropped. The quad-pane windows have R-8 rated insulation values with two options for solar heat gain coefficients (SHGC). Their weight is similar to that of double-pane windows of comparable size and they have the same thickness. The thin glass is also available without the frame and can be used in curtain-wall applications. The windows are made in America and were provided by Alpen High Performance Products. They are suitable for both fixed and operable window applications.

What We Did

COMPARED MEASURED DATA TO MODELED PERFORMANCE

In December 2019, GSA retrofitted ten windows at Denver Federal Center's Building 41, a 498,000 ft^2 two-story office building: five quad-pane windows with suspended film and five windows with thin glass. Researchers measured glass and frame surfaces to compare and calibrate measurements with models created using Department of Energy WINDOW and THERM software. Simulated results included U-factor, SHGC, visible light transmission (VT), and condensation resistance (CR). The U-factor of glazing measures a window's capacity to insulate; the smaller the U-factor, the better the insulation. The SHGC references the fraction of solar radiation that flows through the window from direct sunlight. VT refers to the amount of light that passes through a window. CR measures how well a window resists interior condensation. The higher the number, the better the resistance. SHGC was optimized, in the modeling, for cooling- and heating-dominated climates. Researchers also assessed occupant comfort, ease of installation, and overall cost-effectiveness.

FINDINGS

24% AVERAGE HVAC ENERGY SAVINGS Energy use modeled for a large office building (498K ft²) across climate zones demonstrated savings of between 19% and 34% for the quad-pane windows compared to a high-performance double-pane window. On average, the quad-pane with film saved 1% more energy than the quad-pane with thin glass.

REDUCED HVAC CAPACITY REQUIREMENTS Installing higher-performing windows in new construction or as part of a major renovation can reduce the required size of HVAC equipment. In the modeling for a large office building (498K ft²), required HVAC capacity was reduced ~8% for heating and ~18% for cooling, resulting in a reduction in the capital cost of HVAC equipment by ~$120K.

SAME THICKNESS AND WEIGHT AS DOUBLE PANE The form factor and installation requirements of the quad-pane window are the same as for a typical double-pane window. The weight of the quad-pane thin-glass configuration is comparable to that of a double-pane window, and the suspended film configuration is about 1 lb lighter per square foot than the thin-glass option.

RETURN ON INVESTMENT ACROSS CLIMATE ZONES AND UTILITY RATES With an incremental cost difference of $2.49/ft² for quad-pane with thin glass and $4.49/ft² for quad-pane with suspended film ($32.38/ft² for double-pane, $34.87/ft² for quad-pane with thin glass, and $36.87/ft² for quad-pane with film) payback was between 1 and 6 years, depending on climate zone and utility rates. Even with slightly lower savings, the thin-glass configuration at the lower price point was more cost-effective.

RECOMMENDED FOR NEW CONSTRUCTION AND END-OF-LIFE REPLACEMENT Quad-pane windows are broadly recommended for both new construction and end-of-life replacement. At current pricing, the thin-glass configuration is more cost-effective, but the suspended film version offers more versatility in low-e coatings, provides better UV protection, and is a better option when tempered glass is a requirement. The film version is also lighter, about 1 lb per square foot lighter when compared to thin glass.

Positive Return on Investment Across Climate Zones

New construction payback < 3 years at average GSA utility rates, $0.11/kWh and $7.43/MMBtu

Location		Savings from High-Efficiency Double-Pane to Quad-Pane Thin Glass*					
CLIMATE ZONE	CITY	HEATING kBtu/ft²/yr	COOLING kBtu/ft²/yr	FAN kBtu/ft²/yr	TOTAL %	PAYBACK* YRS	SIR positive ROI if >1
1A	Miami, FL	0.64	2.29	1.61	19%	1.7	12.1
2A	Houston, TX	1.09	2.36	1.59	20%	1.5	12.9
2B	Phoenix, AZ	1.13	2.16	2.00	25%	1.5	13.3
3A	Atlanta, GA	1.97	2.31	1.65	24%	1.4	14
3B	Las Vegas, NV	1.54	1.82	2.08	27%	1.6	12.7
3C	San Francisco, CA	1.95	2.00	1.78	33%	1.5	13.1
4A	Baltimore, MD	3.25	2.48	1.66	28%	1.3	15.5
5A	Chicago, IL	4.40	0.56	1.21	23%	2.5	7.9
5B	Boulder, CO	3.62	0.68	1.43	23%	2.4	8.3
6A	Minneapolis, MN	4.96	0.55	1.17	20%	2.5	8.1
AVERAGE SAVINGS		**2.46**	**1.72**	**1.62**	**24%**	**1.8**	**11.8**

*Optimized for climate zones: 1A-3C SHGC 0.20, 1A-3C SHGC 0.46. $32.38/ft² double-pane $34.87/ft² quad-pane with thin glass $36.87/ft² quad-pane with film
Higher-efficiency windows can reduce HVAC capacity requirements and should be factored into the economics of any new construction or major renovation project.

CONCLUSIONS

These Findings are based on the report, "Demonstration and Evaluation of Lightweight High Performance Quad-pane Windows," which is available from the GPG program website, www.gsa.gov/gpg

For more information, contact GSA's GPG program gpg@gsa.gov

Technology for testbed measurement and verification provided by Alpen High Performance Products.

What We Concluded

AN IMPROVED BUILDING ENVELOPE IS CRITICAL TO ACHIEVING NET-ZERO GOALS

Improving the building envelope is crucial to putting the United States on a path to achieving net-zero emissions. But since the advent of low-e double pane windows in the 1990s, windows haven't improved much. Until now, triple- and quad-pane windows have been more expensive, heavier, and thicker than the incumbent double-pane technology, and have seen little adoption in the U.S. market. Advances in film and thin-glass technology, however, have now made lightweight quad-pane windows a cost-effective alternative and offer a real opportunity to improve the building envelope and contribute to a net-zero economy.

Modeling demonstrates that both configurations of quad-pane windows evaluated here can save energy and be cost-effective throughout GSA's portfolio. Because the cost of thin glass continues to decline, the quad-pane windows with thin glass are currently more cost-effective than the film configuration and more broadly recommended. That said, window replacements can be expensive, so for windows that have not yet reached end-of-life, a secondary window insert made with thin glass may be a better option. See GPG-049 for an evaluation of lightweight high-performance secondary windows offered by the same manufacturer.

Best Practices

- Higher-efficiency windows can reduce HVAC capacity requirements and should be factored into the economics of any new construction or major renovation project.
- Window configuration should be customized for different climates, particularly the solar heat gain coefficient (SHGC). Windows with a high SHGC collect solar heat more effectively and are more broadly recommended for heating-dominated climates. Windows with a low SHGC block heat gain more effectively and are better suited to cooling-dominated climates.